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Economic Impacts of Selected Erosion Control
Policies: Distribution Among Corn Belt States

Illinois Univ. at Urbana-Champaign

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Environmental Research Lab.
Athens, GA

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ECONOMIC IMPACTS OF SELECTED EROSION CONTROL POLICIES:
DISTRIBUTION AMONG CORN BELT STATES

by

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Contract Number 68-03-2597

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FOREWORD

As environmental controls become more costly to implement and the penalties of judgment errors become more severe, environmental quality management requires more efficient management tools based on greater knowledge of the environmental phenomena to be managed. As part of this Laboratory's research on the occurrence, movement, transformation, impact and control of environmental contaminants, the Technology Development and Applications Branch develops management and engineering tools to help pollution control officials achieve water quality goals through watershed management.

Agricultural sources contribute significantly to water pollution problems in many areas of the United States. This report describes part of a 2-year study in which the social, economic, legal and institutional issues involved in the management and control of pollutants from agricultural nonpoint sources were examined.

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David W. Duttweiler
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ABSTRACT

If states in the corn-belt adopt varying soil loss limits as a part of a non-point source of water pollution program, will there be adverse economic consequences? If so, what types of impacts would be felt and would they be severe? The objective of this analysis was focused on such questions.

This analysis was conducted by modifying a large, market-oriented linear programming model of crop production in the corn-belt to allow the imposition of soil loss restrictions at the state as well as the regional level. The results of this analysis indicate that there will not be significant shifts of resources among states if limits are adopted in some states and not in others. Any important regional impacts would occur in small areas where highly erosive soils are concentrated. Farmers in these areas may be forced to change enterprises or adopt less profitable production techniques.

This report was submitted in partial fulfillment of Contract No. 68-03-2597 by the Institute for Environmental Studies, University of Illinois, Urbana-Champaign. The work was conducted with the cooperation of the Illinois Agricultural Experiment Station. The report covers the period September 1977 to August 1979.

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ACKNOWLEDGMENTS

We wish to express our appreciation to C. R. Taylor, Texas A & M University, and K. K. Froberg, University of Gottingen, West Germany, for their assistance in modifying the quantitative model used in the study. We also wish to express our appreciation to the Illinois Soil Conservation Service and to Mr. Homer Kuder, formerly of that organization, for their assistance in developing the soil loss coefficients used in the study. Finally, the support of the Agricultural Experiment Station, University of Illinois, is recognized.

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INTRODUCTION

This report will examine the economic impacts on and expected change in agriculture if various agricultural nonpoint-source control strategies are implemented by different states. The report focuses on soil erosion as an indirect contributor to the nonpoint-source pollution problem.

Because individual states and areas within states are preparing separate water-quality plans under P.L. 92-500, it is possible that there may be variations in the degree to which erosion and sedimentation are controlled in the different states and areas. It is therefore important to see what spatial economic impacts may occur if different states apply different degrees of control.

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This report focuses on Illinois and Wisconsin as subareas of the corn-belt region of the United States. The research on which this report is based--a continuation of work done with the corn-belt model under USEPA contract 68-01-3584--investigated a number of different policies with a modified version of the corn-belt model. These policies included the application of per-acre soil-loss restrictions: (1) only in Illinois, (2) only in Wisconsin, (3) uniformly in all areas of the Corn Belt, excluding Illinois, and (4) uniformly in the entire Corn Belt. The policies were aimed specifically at soil-erosion control because the relationships between erosion-control policies and water quality have not yet been well defined.

A model of the corn-belt economy was used which accounts for production costs, soil erosion, and demand functions for corn and soybeans. As a result, prices for crops can change as production changes. The model predicts soil loss and responds to soil loss restrictions.

This study predicts that the application of soil-loss restrictions in different states in the Corn Belt will result in relatively low costs to society. The costs will be borne by producers under some circumstances and by consumers in others. An important factor in determining who bears the costs is how crop prices and production change. Soybean prices will undoubtedly increase when soil-loss restrictions are applied because it is the most erosive of the major crops grown in the corn-belt. The distribution of crops across various soil types at the time of application of a soil loss restriction will affect changes in crop prices and the distribution of costs between producers and consumers.

In general, the impacts on the various states' shares of farm income in the Corn Belt will be relatively small. Costs to producers will not be evenly distributed within a state. Costs will be concentrated on the owners of more erodible soils. The income of owners of less erodible soils could actually increase if crop prices increase.

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Soil loss will decrease in areas applying soil loss restrictions. In some cases, due to crop shifts between states, soil losses could increase in areas not applying soil loss restrictions.

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Finally, market incentives and educational programs may encourage farmers to adopt conservation tillage practices and reduce soil loss without government intervention. In many instances, supplementary conservation practices would be needed to reduce soil losses to SCS t-values.

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METHOD

A linear programming model of the corn-belt economy was used to investigate the policies. It was a modification of one designed by C. R. Taylor to investigate policies for controlling nonpoint sources of pollution in the Corn Belt (Taylor and Frohberg, 1977; Seitz et al., 1978). The model was applied to 17 land resource areas (LRAs) that produce approximately 70% of U.S. corn production and 60% of U.S. soybean production (Swanson and Taylor, 1976). Modifications to the model consisted of separating the state of Illinois from other areas of the Corn Belt, incorporating a new method of including demand functions, and updating soil-loss coefficients.

Structure of the Modified Corn-Belt Model

The objective function in the model was producers' plus consumers' surpluses from the production of corn and soybeans minus the costs of production to meet requirements for wheat, oats, and hay. This function was maximized subject to the restrictions of the land base and environmental controls. For purposes of this paper, changes in consumers' surplus are equivalent to changes in consumer expenditures. When consumers' surplus increases, consumer expenditures decrease. Changes in producers' surplus are equivalent to changes in farm income. When producers' surplus increases, farm income increases. The model was composed of two interdependent components that operated simultaneously: (1) a component that determined requirements for corn and soybeans and (2) a component that minimized the costs of producing corn, soybeans, wheat, oats, and hay to meet requirements on a fixed land base. Demand functions were not included for wheat, oats, and hay because it was costly to derive them for this study and these crops were considered to be less important in the Corn Belt than corn and soybeans.

The component that determined requirements for corn and soybeans was defined by linear-demand functions for corn and soybeans, as specified in Taylor and Frohberg (1977) and Seitz et al. (1978) after review of a number of demand analyses. These demand functions were included in the modified corn-belt model, using a method described by Duloy and Norton (1975), a method conceptually equivalent to—but computationally more efficient than—that used by Taylor and Frohberg (1977). As under the corn-belt model, the demand functions were divided into a series of steps, but in the modified model an area under the demand curve was computed for each step. The total area under each demand curve was determined for the combination of price and quantity for each step and was a definite integral over quantity from zero to the quantity sold for each step. The algorithm maximizes the sum of the areas under the demand curves less total production costs.

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The great advantage of this method is that it reduces the total number of constraining rows and thus the computational costs of solving the model.

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Under the stepwise method used in the corn-belt model, two constraining rows were required for each step in the corn-demand function and one row for each step in the soybean-demand function, for a total of 258 rows. Only two constraining rows were required with the new method. With the stepwise method, all activities describing the demand functions were active in solution up to the last step at the equilibrium price. In the modified model, no more than two activities can be active at any time. Corn yields and nitrogen-fertilizer-application rates were corrected in the rows of both the corn-belt and modified corn-belt models.

Requirements for wheat, oats, and hay were determined outside of the model. Hay requirements were set for each LRA, while the requirements for wheat and oats were established for the entire Corn Belt. With the application of soil-loss constraints, land was removed from production, and it was assumed that land removed from row-crop production because of the soil-loss constraints would be allocated to hay production, thus producing revenue for the landowner.

Each production activity in the cost-minimizing component was a crop rotation combined with a tillage practice and a conservation practice and was applied to a land capability unit (LCU) in a land resource area (LRA). Tillage practices included fall moldboard plowing, spring moldboard plowing, and chisel plowing. Conservation practices included straight-row plowing, contouring and terracing, but terracing was limited to those LCUs on which it was an appropriate technique. Moreover, because insect problems associated with conservation tillage, specifically the spread of cutworm, were not accounted for, costs for conservation tillage may be understated. These costs, however, were not considered to be a major obstacle to the use of conservation tillage.*

The State of Illinois was defined by calculating the acreage of each LCU in an LRA within the State (Soil and Water Conservation Needs Committee of Illinois, 1970). Because the Illinois portions of LRAs 95 and 105 are quite small, they were aggregated with LRA 108 to lower computation costs. Some of the relatively minor LRAs outside of Illinois were also aggregated to reduce computation costs. LRA 91 was aggregated with 95, 103 with 104, and 114 with 115.

Figure 1 is a map of the Corn Belt with the 19 production regions outlined. Costs and yields for each LCU in each of the LRAs to be aggregated were weighted by the area of the LCU in the LRA to compute an average cost and yield for the LCU in the aggregated region. Hay requirements for regions to be aggregated were summed to compute the requirement for the aggregated regions. Hay requirements for LRAs 95 and 105 were disaggregated into regions inside and outside Illinois according to the proportions of the LRA's. The additional costs of estimating demand functions for these crops and the additional computational costs in running the model were felt to be unjustified for this study.

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*Moore, Steve. 1977. Personal correspondence. Extension entomologist, Illinois Natural History Survey, Urbana, Illinois.

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Figure 1. Major land resource areas of the Corn Belt.

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area inside and outside Illinois. The hay requirements of the two LRA's estimated for regions in Illinois were summed to the requirements for LRA 108 in Illinois and subtracted from requirements outside Illinois.

The area of the State of Wisconsin within the Corn Belt was approximated by LRAs 91, 95, and 105 outside of Illinois. There was no attempt to separate LRA 105 into areas inside Wisconsin and outside Wisconsin. As a result, the acreage of cropland in Wisconsin is overstated in this model.

Soil-loss coefficients used in this study were updated from those used in Seitz et al. (1978). The Soil Conservation Service has changed the inputs to the Universal Soil Loss Equation in recent years.² Some of the assumptions concerning slope and slope length in LCUs and LRAs were changed in this study. Inputs for the Universal Soil Loss Equation were obtained from Lee (1976) and Kuder.*

A detailed discussion of the model is provided in the Appendix.

Definition of Terms Used and Assumptions Required in Analysis

Since the modified corn-belt model used a method of including demand curves different from that of the original corn-belt model, some slight changes in the definition of economic variables, particularly a change in consumers' surplus, were necessary:

$$\text{Social cost} = -1(\Delta\text{PS} + \Delta\text{CS})$$

(Social cost sums the changes in consumer expenditures and farm income, netting out income transfers between producers and consumers.)

In this equation the change in producers' surplus relative to the benchmark solution, ΔPS , is given by

$$\Delta\text{PS} = \sum_{i=1}^5 [(Q_{Ri} \times P_{Ri} - C_{Ri}) - (Q_{Bi} \times P_{Bi} - C_{Bi})]$$

and the change in consumers' surplus relative to the benchmark solution, ΔCS is given by

$$\Delta\text{CS} = \sum_{i=1}^2 [A_{Ri} - Q_{Ri} \times P_{Ri}) - (A_{Bi} - Q_{Ri} \times P_{Ri})] +$$

*Kuder, Homer. 1977. Personal correspondence. Consultant, Illinois Environmental Protection Agency, St. Joseph, Illinois.

2 The new methods of computing soil loss have caused some controversy nationwide in The Resource Conservation Act Assessment. Estimates of soil loss have decreased bringing about some criticism of SCS. See "SCS Answers Critics of New Soil and Water Data: The Numbers Controversy-Background" USDA Issue Briefing Paper No. 2, Aug. 21, 1979, Off. of Govt. & Public Affairs, D.C.

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$$\sum_{i=3}^5 (Q_{B1} \times P_{B1} - Q_{R1} \times P_{R1})$$

where

A_{B1} = area under demand curve for commodity 1 for benchmark run

A_{R1} = area under demand curve for commodity 1 for soil-loss restriction

C_{B1} = cost of commodity 1 in the benchmark run

C_{R1} = cost of commodity 1 with soil-loss restriction

P_{B1} = price of commodity 1 with benchmark run

P_{R1} = price of commodity 1 with soil-loss restriction

Q_{B1} = quantity of commodity 1 produced with benchmark run

Q_{R1} = quantity of commodity 1 produced with soil-loss restriction

i = commodity; $i = 1$ for corn, $i = 2$ for soybeans, $i = 3$ for wheat,
 $i = 4$ for oats, and $i = 5$ for hay.

The prices of corn and soybeans were determined by the objective function. The prices of wheat, oats, and hay were shadow prices determined within the model. To add producers' and consumers' surpluses and to make comparisons of social costs between runs, it was assumed that a dollar has the same value to all individuals. Social cost, however, does not account for the environmental benefits and administrative costs brought about by a policy.

Focus on Spatial Economic Impacts of Soil-Loss Restrictions

Under the previous contract, the corn-belt model was used to investigate a large number of erosion-control policies, including soil-loss taxes, soil-loss restrictions, and terracing subsidies and cost sharing. The results indicated that, in terms of social costs, soil-loss taxes were more efficient than soil-loss restrictions, which, in turn, were more efficient than subsidies and cost sharing. Both soil-loss restrictions and terracing subsidies increased producers' surplus (or had small negative impacts) and decreased consumers' surplus, while the opposite occurred with a soil-loss tax. Soil-loss restrictions and subsidies had very similar results except that the terracing subsidies encouraged more terracing, which, in some situations was a less cost-effective means of reducing soil loss. Soil-loss restrictions and cost sharing or subsidies, moreover, are more likely to be implemented than soil-loss taxes since it is difficult to determine charges per ton and assign taxes to landowners under a soil-loss tax. As a result, further analysis of soil-loss taxes was not carried out under this study. Since restrictions and cost sharing (and subsidies) behave similarly except for

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some differences in the burden of cost and choice of land practices, the decision was made to concentrate the analysis on the spatial economic impacts of soil-loss restrictions.

Assumptions about Soil Loss under Different Policies

A number of policies were run only in the State of Illinois, including 6.72-, 8.97-, and 11.21-metric-ton-per-hectare-per-year (MTHY) (3-, 4-, and 5-ton-per-acre-per-year [TAY]) soil-loss restrictions and a 6.72-MTHY (3-TAY) restriction combined with a 50% cost sharing of terracing. The results of all these policies showed similar trends so that only the 6.72-MTHY (3-TAY) restriction in Illinois (policy I) will be discussed in this report.

A benchmark solution estimated what would occur under market conditions with no environmental-control policies. In addition, three other policies were examined: a 6.72-MTHY (3-TAY) restriction in all corn-belt states except Illinois (policy NI), a 6.72-MTHY (3-TAY) restriction applied in the entire Corn Belt (policy CB), and a 6.72-MTHY (3-TAY) restriction applied only in Wisconsin (policy W).

Assumptions About the Benchmark

Under the benchmark solution, producers' surplus was \$8.116 billion, while consumers' surplus was \$11.001 billion. The correspondence between areas of actual and benchmark crop production by LRA was similar in degree to Taylor's and Frohberg's results (1977), but there were some minor regional differences. The modified corn-belt model allocated considerably more soybeans and less corn to LRAs 98 and 106 than the original corn-belt model, while the opposite occurred in LRAs 103 and 110. These differences partially explain the differences between some of the results in this report and those in the previous report (Seitz et al., 1978), as discussed later.

Assumptions about Conservation Practices

The model predicted that no land would be terraced or contoured because these conservation practices increase the per-hectare cost of production without changing current yields. Future costs and benefits of conservation practices were not considered.

No yield adjustments were made for any of the tillage or conservation practices. However, some cost adjustments were made. There was a 10% increase in labor over straight-row plowing assumed for contouring and 20% for terracing. Some adjustments in labor costs were made for tillage practices. Labor costs for spring plowing (conventional tillage) increased by 5% in LRAs 97 and 98 and decreased by 5% in LRA 103 and 10% in LRA 109 with respect to fall plowing (conventional tillage). Labor costs for conservation tillage decreased from 10% to 25% depending upon the LRA, averaging about 15%. Also an additional charge of \$0.90 per acre was assumed for contouring, while construction and maintenance costs, amortized over 20 years, were added for terracing.

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Under the benchmark, approximately 74% of Illinois land in cultivation and 50% in Wisconsin were under conservation tillage (chisel plowing), because the reduced labor costs of conservation tillage (relative to conventional tillage) lowered the per-hectare production costs relative to conventional practices. The average soil loss on cropland planted in Illinois was estimated to be 6.66-MTHY (2.97 TAY) and in Wisconsin to be 9.93-MTHY (4.43 TAY).

Estimates by other researchers of the current condition of land use and soil loss are somewhat different. Kuder* estimated that the average soil loss on Illinois cropland under current conditions is 11.43 MTHY (5.1 TAY), and Ives** estimated that in Illinois there are less than 101.175 hectares (250,000 acres) of terraced land as compared with approximately 0.53 million hectares (1.3 million acres) of contoured land. Lessitor (1976) reported that approximately 28% of Illinois cropland and 16% of that in Wisconsin was chisel plowed in 1976.

The large acreage in conservation tillage in the benchmark as compared to the actual situation accounts for the low estimate of soil loss in this study. The model implies that there may be a substantial increase in conservation tillage in Illinois and throughout the Corn Belt because of the resulting lower labor and fuel costs. This increase in conservation tillage may bring about a large decrease in soil loss without a change in government soil-erosion control policies.

There are a number of reasons why farmers have not yet adopted conservation tillage to the degree predicted by this model. This is still some controversy concerning how effective the practice really is. Not all farmers really know or believe how effective the practice might be. In addition, pest control problems may arise from the use of conservation tillage. There are some constraints to the adoption of conservation tillage. It takes time for farmers to replace their equipment with conservation tillage equipment. Also, some absentee landlords may be opposed to the practice because it does not look as clean as conventional tillage, thus restricting tenants' options to use the practices. However, more and more farmers have been adopting some form of conservation tillage (Lessitor, 1976). Options to encourage the implementation of a variety of conservation practices were discussed in Seitz et al. (1978).

ANALYSIS OF RESULTS OF SOIL-EROSION CONTROL POLICIES

This study shows that if soil-loss restrictions are applied, two components would have important impacts on prices: (1) the area of application and (2) the distribution of crops over different soil types. Soil-loss restrictions would require that erosion-control practices be used with some crop rotations on some LCUs. These erosion controls would increase the costs of producing crops, and these cost changes would have impacts on crop prices, production, and acreages. Furthermore, because crops would have varying erosion rates, soil-loss restrictions would have different impacts on the

*Kuder, Homer. 1977. Personal correspondence. Consultant, Illinois Environmental Protection Agency, St. Joseph, Illinois.

**Ives, Freeland. 1977. Personal correspondence. Civil Engineer, Soil Conservation Service, Champaign, Illinois.

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prices of each crop. Thus the relative returns of crops would change, and farmers would change their production mixes in such a way as to maximize income under the constraint.

Table 1 illustrates commodity prices and commodity production for each policy. Soybean production would decrease and price increase as the area of the restriction increased from policy I to policy NI to policy CB. Corn price and production would also increase under policy I, but the opposite would occur under policies NI and CB. While the prices of wheat, oats, and hay generally decrease if soil-loss restrictions were applied, a pattern of price changes was not readily apparent. Prices and production would not change under policy W.

Since soybean production would generate higher soil-erosion rates than other crops, the cost of meeting the restriction would be higher with soybean production than with other crops; thus soybean production would decrease under policies I, NI, and CB. Because decreased soybean production would open land for the production of the other crops, prices of wheat, oats, and hay would decrease with shifts to more fertile land. Corn would also be allocated to this land in policies NI and CB if corn production increased.

The changes in prices and production would affect producers' and consumers' surpluses. For example, the analysis showed the decrease in consumers' surplus with Policy I to be the result of the small increases of corn and hay prices while other prices remained constant. The increase of corn and hay prices in the price-inelastic portions of demand curves would also increase producers' surplus. Consumers' surplus would not change under policy W, however, because crop prices would not change.

The decrease in all prices except soybeans relative to the benchmark in policies NI and CB would result in an increase in consumers' surplus. Soybean price would increase in the price-elastic portion of its demand curve, while the prices of other crops would decrease in price-inelastic areas, causing gross revenue to decrease. The decrease in revenue and the increase in erosion-control costs, therefore, would cause producers' surplus to decrease in policies NI and CB.

The changes in producers' and consumers' surpluses resulting from a 6.73 MTHY (3-TAY) soil loss restriction throughout the Corn Belt predicted by this study differ from those under Seitz et al. (1978). Soybean price increased (and production decreased) and corn price decreased (and production increased) relative to the benchmark under this study while the prices of both crops increased under Seitz et al. (1978). The reason for the difference in crop price and production changes between the two studies is due to the difference in distribution of crops over soil types under benchmark conditions.³

³ It appears that the primary reason for the difference in crop patterns between this study and Seitz et al. (1978) is the aggregation of LRAs required under this study. LRAs were aggregated to reduce the size and cost of the model in order to highlight state boundaries while staying within time and cost constraints of the study. As a result of averaging costs and yields (and thus economic incentives), crop production and distribution to maximize the

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Table 1. Changes in Economic Variables Due to Soil-Erosion Policies

	Changes from Benchmark Due to 3-TAY Soil-Loss Restriction				
	Bench- mark	Policy I	Policy NI	Policy CB	Policy W
Social Cost (million \$)	0	15.0	48.0	64.0	6.0
Consumers' Surplus (million \$)	0	-49.6	291.0	258.0	0
Producers' Surplus (million \$)	0	36.4	-339.0	-322.0	-6.0
Production Cost (million \$)	0	6.0	2.0	26.5	6.0
Gross Revenue (million \$)	0	36.3	-337.0	-295.0	0
Commodity Prices*					
Corn (\$/g x 10 ⁴)	1.01	1.02	0.99	0.97	1.02
Soybeans (\$/g x 10 ⁴)	2.01	2.01	2.12	2.16	2.01
Wheat (\$/g x 10 ⁴)	1.78	1.78	1.55	1.64	1.78
Oats (\$/g x 10 ⁴)	1.64	1.64	1.41	1.43	1.64
Hay (\$/metric ton)	56.87	57.01	54.31	54.85	56.87
Commodity Production					
Corn(g x 10 ¹³)	9.30	9.28	9.40	9.54	9.30
Soybeans (g x 10 ¹³)	2.07	2.06	1.96	1.92	2.07
Wheat (g x 10 ¹³)	.617	.617	.617	.617	.617
Oats (g x 10 ¹³)	.539	.539	.539	.539	.539
Hay (million metric ton)	23.52	23.70	24.73	24.91	23.52

*The weights of the commodities assume that one bushel of corn weighs 56 pounds (1b), one bushel of soybeans 60 lb, one bushel of wheat 60 lb, and one bushel of oats 32 lb.

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In this study, more soybeans and less corn were allocated to areas with more erodible soils (such as LRAs 98 and 106) under the benchmark solution than in Seitz et al. (1978), while the opposite occurred in areas with less erodible soils. When soil loss restrictions were applied, corn was substituted for soybeans, while small grains and hay were substituted for both corn and soybeans to reduce soil loss. However, due to the differences in the distribution of crops over soil types between the two studies, more corn was substituted for soybeans and less small grains and hay were substituted for corn in this study than in Seitz et al. (1978). Because more corn is allocated to less erodible soil and more soybeans to more erodible soils under this study, less land producing corn required a crop substitution to meet a 6.73 MTHY (3-TAY) soil loss restriction than under Seitz et al. (1978). Also, more corn was substituted for soybeans to meet the soil loss restriction under this study. As a result, corn production actually increased under this study while it decreased under Seitz et al. (1978).

The results of both studies are plausible. The same types of crop substitutions took place with both studies; only the relative sizes of the substitutions were different. In addition, the economic impacts of both studies were small, as will be illustrated later. One important implication of the difference in results between the two studies is that changes in crop prices and related economic impacts resulting from the application of a soil loss restriction would be sensitive to the distribution of crops over soil types.

Economic Impacts in the Corn Belt

The results show that with all policies society would bear a cost to control soil erosion. Producers and consumers, however, would not share the cost equally, and the incidence of the cost would change with the area of application of the soil loss restriction.

As shown in Table 1, with policy I, producers' surplus would increase and consumers' surplus would decrease, while the opposite would occur with policies NI and CB. With policy W, producers' surplus would decrease, while consumers' surplus would remain unchanged. The social cost would be \$6 million for policy W, \$15 million for policy I, \$48 million for policy NI, and \$64 million for policy CB.⁴

Producers' surplus would increase by \$36.4 million with policy I, and decrease by \$6 million with policy W, by \$339 million with policy NI, and by \$322 million with policy CB, as compared to the benchmark. Consumers' surplus would decrease by \$49.6 million with policy I, increase by \$29.1 million with policy NI and by \$258 million with policy CB, and remain unchanged with

3 (cont.) objective functions were different under the benchmark of this study than Seitz et al. (1978). Also, the computations needed to install the Dulay and Norton (1975) method may have contributed to a change in economic incentives.

4 While these social costs appear to be much lower than social costs estimated with low soil constraints under Seitz et al. (1978), the difference consists almost entirely of revenue from hay grown on land removed from production by the algorithm, which was not accounted for in the previous study.

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policy W. Consumers' surplus increases under policies NI and CB because the prices of corn, small grains, and hay decreased even though the price of soybeans increased. The increase in soybean price caused a decrease in consumers' surplus which was more than offset by an increase in consumers' surplus caused by the decrease in prices of corn, small grains, and hay. An important factor was that small changes in corn price had a large impact on consumers' surplus. This occurred because corn had the largest acreage and volume of production among crops in the Corn Belt. Thus small decreases in corn price affected the returns on all corn produced and resulted in a large increase in consumers' surplus. However, the increase in consumers' surplus brought about by the decrease in corn price was not large enough to offset the decrease in consumers' surplus brought about by the increase in soybean price. The decreases in prices of small grains and hay were needed to bring about the overall increases in consumers' surplus under policies NI and CB.

With policies NI and CB, consumers' surplus would increase while producers' surplus would decrease. These results conflict with the findings of Seitz et al. (1978) that producers' surplus would increase while consumers' surplus would decrease if a soil-loss restriction were applied in the Corn Belt. The reason for these differences was discussed in the previous section on prices and production.

Regional Economic Impacts

The results predicted very little impact on both Illinois' and Wisconsin's comparative advantages in crop production with all policies. Decisions to control erosion within either state would have small impacts on producers' surplus and share of producers' surplus within each state. However, the application of a soil-loss restriction within either state would decrease each state's share of producers' surplus slightly. The application, however, of a 6.73-MTHY (3-TAY) restriction in large numbers of states in the Corn Belt would have impacts on producers' surplus in both Illinois and Wisconsin. Producers' surplus and share of producers' surplus in Wisconsin would increase if large areas outside of its borders applied a 6.72 MTHY (3-TAY) restriction. In Illinois, if large areas outside of its borders applied a 6.72 MTHY (3-TAY) restriction, producers' surplus would decrease but share of producers' surplus would change very little.

Analysis showed the impacts of the policies on Illinois' and Wisconsin's shares of producers' surplus to be the result of price changes, erosion-control costs, and shifts of production between regions. Price changes would have the same impact on per-acre returns in areas that applied soil-loss restrictions and in those that did not. As a result of the costs of erosion-control practices, in areas that applied soil-loss restrictions, producers' surplus would decrease relative to those areas that did not apply the restrictions. Erosion-control costs also would change economic incentives for crops in different regions, causing production shifts, particularly if large areas applied soil-loss restrictions.

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The small impact on Illinois' comparative advantage is demonstrated in Table 2 by the small change in Illinois' share of producers' surplus for all policies as compared to the benchmark. Under the benchmark, Illinois'

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producers' surplus was \$1.996 billion, which is 24.6% of producers' surplus for the Corn Belt. Producers' surplus in Illinois would remain the same with policy W. It would decrease by \$47 million (to 23.9%) with policy I, by \$113 million (to 24.2%) with policy NI, and by \$133 million (to 24%) with policy CB. Thus the maximum decrease in Illinois' share of producers' surplus would be 0.7%.

The impact of all policies on Wisconsin's comparative advantage would also be small. With the benchmark, Wisconsin had a producers' surplus of \$427 million, which is 5.3% of producers' surplus in the Corn Belt. Producers' surplus in Wisconsin would increase by \$3 million with policy I (to 5.3%), by \$1 million with policy NI (to 5.5%), and by \$6 million with policy CB (to 5.6%), and decrease by \$6 million under policy W (to 5.2%). Thus the maximum range of Wisconsin's share of producers' surplus from the benchmark would be 0.4%. One interesting result is that producers' surplus in Wisconsin would increase under policies NI and CB while it would decrease in Illinois. These results are also shown in Table 2.

Comparing policies shows that producers' surplus would be greater in each state if it did not apply a soil-loss restriction than if it did. In Illinois, producers' surplus was \$6.6 million greater with the benchmark than with policy I, when states outside of Illinois did not apply a restriction. Also, if states outside of Illinois did apply a restriction, producers' surplus would be \$20 million greater with policy NI than with policy CB. The same sort of pattern developed in Wisconsin. Producers' surplus in Wisconsin would be \$6 million greater with the benchmark than with policy W, when states outside of Wisconsin did not apply a restriction.

The application of a soil-loss restriction in large areas of the Corn Belt had important impacts on producers' surplus within each state. In Illinois, under policies NI and CB, there would be a large decrease in producers' surplus, greater than \$100 million. Illinois' share of producers' surplus would change little, however, because producers' surplus outside of Illinois would also decrease by a large amount. In Wisconsin, producers' surplus would actually increase by \$1 million under policy NI and \$6 million under policy CB.

Production changes would include shifts in crop production among regions in the Corn Belt, and such shifts have impacts on producers' surplus within a state if large areas of the Corn Belt apply a soil-loss restriction. These production shifts would be the result of attempts in some areas to reduce soil loss in a cost-effective manner. In many situations, it would be cheaper to change crop rotations, substituting crops that encouraged less erosion for those that encouraged more, than to apply some conservation practices. Farmers in other areas would find it advantageous to increase the production of more erosive crops because of their prices. Shares of crop production in Illinois and Wisconsin are also shown in Table 2.

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Under policies NI and CB, soybeans would be substituted for corn in Illinois, while the opposite would occur outside Illinois. Illinois' share of corn production would decrease slightly relative to the benchmark and policy W under policies I, NI, and CB, with greater decreases under policies

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Table 2. Shares and Changes of Producers' Surplus and Shares of Crop Production for Illinois and Wisconsin

	Bench- mark	Policy I	Policy NI	Policy CB	Policy W
Changes in Producers' Surplus					
Illinois (million \$)	0	-47	-113	-133	0
Wisconsin (million \$)	0	+ 3	+ 1	+ 6	-6
Share of Producers' Surplus					
Illinois	.246	.239	.242	.240	.246
Wisconsin	.053	.053	.055	.056	.052
Illinois' Share of Crop Production					
Corn	.250	.249	.245	.241	.250
Soybeans	.149	.148	.161	.162	.149
Wheat	.324	.324	.324	.324	.324
Oats	.237	.198	.213	.235	.237
Wisconsin's Share of Crop Production					
Corn	.048	.048	.060	.059	.048
Soybeans	.026	.026	.038	.039	.026
Wheat	.108	.108	.081	.084	.108
Oats	.159	.159	.069	.068	.159

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NI and CB. Total corn production would also decrease. Illinois' share of soybean production would increase from approximately 15% for the benchmark and policies I and W to 16% for policies NI and CB. Wheat and oats showed no definable pattern.

To reduce erosion-control costs, farmers outside of Illinois would substitute corn for soybeans since corn encourages less erosion, thus reducing erosion-control costs to meet soil-loss restrictions. The results would be a decrease in corn price and an increase in soybean price. With policy NI, Illinois farmers would find it advantageous to substitute soybeans for corn as a result of the price changes. With policy CB, the flat land in Illinois became a factor. On this flat land, erosion rates are less than on lands outside Illinois, thus reducing potential erosion-control costs for soybeans relative to land outside of Illinois. So, with policy CB the changes in relative prices as well as the flat land in Illinois would encourage Illinois farmers to substitute soybeans for corn. With policy CB, however, soybean production in Illinois would be less than with policy NI because of the application of a soil-loss restriction in Illinois under the latter policy.

At the same time, under policies NI and CB, corn and soybeans would be substituted for small grains in Wisconsin. Wisconsin's share of corn production would increase from approximately 4.8% with the benchmark and policies I and W to approximately 6% for policies NI and CB. Wisconsin's share of soybean production would increase from 2.6% for the benchmark and policies I and W to approximately 4% with policies NI and CB. Wisconsin's share of wheat production would decrease from 10.8% with the benchmark and policies I and W to just over 8% with policies NI and CB. Oat production would decrease from 15.9% for the benchmark and policies I and W to approximately 7% for policies NI and CB.

While corn and soybeans would be substituted for small grains in Wisconsin, the reverse would occur on 3E soils in LRA 106 in Kansas and Nebraska and in LRA 113 in Missouri. Small grain production would be shifted to these areas to reduce soil losses because it would be cheaper to change crop rotations than to apply some soil-erosion control practices. Corn and bean production would shift to LRAs 91 and 95 in Wisconsin because these areas have relatively low soil losses as the result of less-intense rainstorms. These commodities would also shift to LRA 105 in Wisconsin because its yields are high relative to other areas in the state. As a result, additional erosion-control costs could be justified in Wisconsin under policies NI and CB.

The shifts in crop production, as well as price changes and erosion-control costs, explain the changes in producers' surplus in different regions. Producers' surplus would decrease only slightly in Illinois with policy I because the prices of corn and hay would increase while Illinois maintained a high share of corn production. These price increases would offset decreases in revenue caused by decreased production of corn, soybeans, wheat, and oats and increased costs of controlling erosion. While the primary reason that Illinois' decrease in producers' surplus with policies NI and CB was larger than with policy I was the decrease in the prices of corn, wheat, oats, and hay, erosion-control costs caused producers' surplus to be lower in Illinois with policy CB than with policy NI. Although it is

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difficult to determine from the results exactly what impact production shifts would have on producers' surplus in Illinois and outside Illinois, it would appear from the relative changes in the prices of corn and soybeans that the shifts would moderate the decrease of producers' surplus in Illinois. Also, the relatively small changes in Illinois' share of production of each crop indicate that the impacts of these production shifts on income would be small.

The small increase in producers' surplus in Wisconsin with policy I as compared to the benchmark was due to small increases in prices of corn and hay with no changes in production patterns and due to the absence of soil-erosion control costs. Thus the small decrease in producers' surplus in Wisconsin with policy W as compared to the benchmark was due to the soil-erosion-control costs needed to meet the 6.72 MTHY (3-TAY) restriction, while prices and production did not change.

The substitution of corn and soybeans for small grains in Wisconsin under policies NI and CB was the primary reason for the increase in producers' surplus and share of producers' surplus in Wisconsin, as compared to the benchmark and policies I and W. This substitution increased producers' surplus because corn and soybeans have greater per-acre returns than small grains. Producers' surplus in Wisconsin was thus higher under policy CB than under NI because soybean price was higher under policy CB.

Economic Impacts within a State

The economic impacts of a soil-erosion policy probably would not be evenly distributed within a state, as was shown in Illinois. The most severe income reductions occurred on land with high slopes and more erodible soils, which are more prevalent in southern Illinois, in general, than in other areas of the state. These areas required more expensive erosion-control practices and changes in crop rotations to meet the soil-loss restriction than flatter land and less erodible soil. These changes had impacts on prices, which, in turn, affected returns per acre on land not needing erosion-control practices or crop-rotation changes. Under some circumstances, however, returns increased on some land and decreased on other land.

Under policy I, average change in returns per hectare would vary from a gain of \$1.16 per hectare (\$0.47 per acre) in LRA 110 to a reduction of \$5.83 per hectare (\$2.36 per acre) in LRA 113. The small gains would be the result of small increases in the price of corn and soybeans. With policy NI, average per-hectare changes in returns would vary from a reduction of \$9.16 per hectare (\$3.71 per acre) in LRA 115 to a loss of \$14.87 per hectare (\$6.02 per acre) in LRA 113. With policy CB, average per-hectare change would vary from a loss of \$10.63 per hectare (\$4.30 per acre) in LRA 114 to a loss of \$26.46 per hectare (\$10.71 per acre) in LRA 113. With policies NI and CB, the prices of all commodities except soybeans would decrease resulting in losses to all land in Illinois. Under policy W, however, returns per acre would not change in Illinois because there would be no price changes in the Corn Belt and no changes in crop production or applications of erosion-control practices in the State itself.

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Table 3. Changes in Returns for LCUs in Illinois (\$/hectare)

LCU	Policy I	Policy NI	Policy CB
1	2.06	-16.31	-16.16
2E	-2.22	-12.60	-17.05
3E	-4.72	-11.32	-18.09
4E	-7.24	-12.38	-12.95
2W	^{6 1/2"} .96	-11.79	-13.71
3W	1.06	- 9.34	-15.74
4W	^{9 1/8"} .49	- 9.09	- 8.55
2S	.27	-14.01	-12.97
3S	- .69	-12.16	-15.54
4S	-1.56	- 7.59	- 5.88
58*	- .32	- 8.57	- 8.10

*LCU 58 is an aggregation of soil classes 5 through 8.

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Table 3 illustrates the average change in returns per hectare over all Illinois LRAs for each LCU with each policy relative to the benchmark and policy W. The most noticeable result was that income gains and reductions would not be evenly distributed among the LCUs. The largest reductions in returns per acre would occur on LCUs 2E, 3E, and 4E (land with an erosion problem and relatively high slope) under policies I and CB because changes in crop rotations and applications of erosion controls would be needed to meet the soil-loss restriction.

The greatest changes in land management and the largest reductions in returns per hectare would occur on LCUs 3E, 4E, and 58 (which aggregated SCS soil classes 5 through 8) in LRA 113, an area in southern Illinois where soils are more erodible than in other areas of Illinois. As a result, economic impacts would be greater in LRA 113 than in other LRAs.

The importance of price impacts on per-hectare returns can be appreciated by comparing the policies. Illinois' per-hectare losses in policies NI and CB would be, in general, considerably larger than in policy I. The differences in per-hectare losses between policies NI and I on W-subclass soils in particular showed that price impacts alone could cause very large changes in per-hectare returns. Soil-erosion-control practices would not be applied to these soils because of their extremely low soil losses. With policy I, all W-subclass soils would show increases in per-hectare returns because of increases in the price of corn, but, with policies NI and CB, the per-hectare returns on these soils would decrease because of price decreases in all crops except soybeans.

Price changes and crop shifts between states can have interesting impacts on income in different regions of a state even when soil-loss restrictions are not applied by the state. Under policy NI, income reductions would be greater in the less erosive sections in northern Illinois than in the more erosive sections in southern Illinois, because corn and soybean production in northern Illinois would change very little. The price of corn, which is the predominant crop in that area, would decrease while soybean price would increase, causing farm income in northern Illinois to decrease. In southern Illinois, because no soil-loss restriction would be applied in the state under policy NI, soybeans would be substituted for corn in response to relatively higher soybean prices. As a result, the income reduction in the more erosive southern region would be less than in the northern region.

Soil Loss and Conservation Practices

Soil-loss restrictions would have impacts on land-management practices as well as on soil loss from land. As expected, soil loss would decrease in areas that applied soil-loss restrictions while soil loss would increase in areas that did not. Moreover, the decrease in soil loss in areas that applied soil-loss restrictions would be greater than the increase in the areas that did not. So, soil loss throughout the Corn Belt would decrease, as shown in Table 4.

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Table 4. Soil Loss Under Each Policy

	Benchmark	Policy I	Policy NI	Policy CB	Policy W
Soil loss outside Illinois (million metric tons)	422.233	442.293	116.526	123.214	426.964
Soil loss in Illinois (million metric tons)	61.230	31.516	70.718	31.550	61.230
Soil loss in Wisconsin (million metric tons)	35.688	35.688	21.553	21.534	20.419
Total soil loss in Corn Belt (million metric tons)	503.465	473.810	187.244	154.769	488.196

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Soil loss in Illinois would decrease with policies I and CB by approximately 29.9 million metric tons (MT) (33 million short tons) relative to the benchmark and policy W. Soil loss outside Illinois would increase by 59.9 MT (66,000 short tons) relative to the benchmark with policy I and decrease by 325.6 million MT (359 million short tons) with policy NI and by 319 million MT (352 million short tons) with policy CB. Thus, soil loss outside Illinois would be 6.7 million MT greater with policy CB than with policy NI.

Under policy W, soil loss in Wisconsin would decrease by 15.2 million MT but would not change elsewhere. Under policies NI and CB, soil loss in Wisconsin would decrease by 14.7 million MT as compared to the benchmark and policy I.

Total soil loss in the Corn Belt would decrease by 15.2 million MT under policy W, by 29.7 million MT under policy I, by 316.2 million MT with policy NI, and by 348.7 million MT under policy CB.

Applying soil-loss restrictions would have a large impact on conservation practices. More than 30% of Illinois' area, more than 65% of Wisconsin's area, and more than 45% of the area outside of Illinois would be shifted into conservation practices (terraces and contouring) if a 6.72-MTHY (3-TAY) restriction were applied. Approximately 0.445 million hectares of land (1.1 million acres) in Illinois would be allocated to terracing and 2.42 million hectares (6 million acres) to contouring under policies I and CB. Approximately 38,450 hectares of terracing (95,000 acres) would be applied in Wisconsin under policies W, NI, and CB, while with regard to contouring, 2.31 million hectares (5.7 million acres) would be applied under policy W and 2.75 million hectares (6.8 million acres) under policies NI and CB. Of the acreage under conservation practices, a much lower proportion would be allocated to terracing in Wisconsin than in Illinois.

The impact of soil-loss restrictions on the acreages under various conservation-tillage practices relative to the benchmark would be less dramatic than the impact on the acreages under conservation practices. This difference is due primarily to the high percentage in all runs, including the benchmark, of conservation tillage, which produces less soil loss than fall and spring plowing.

Summary of the Impacts

Table 5 shows, in generalized terms, the changes in economic impacts and soil losses associated with the alternative policies.

SUMMARY AND CONCLUSIONS

1. The application of soil-loss restrictions in some areas and not in others, as might occur under P.L. 92-500, would bring about variations in economic consequences, but soil-loss restrictions would cause relatively small social costs, ranging from \$6 million for policy W to \$64 million for policy CB. Although the price effects and costs of soil-erosion controls would bring about relatively large decreases in returns to landowners and

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Table 5. Summary of Impacts

	Policy				
	BM	I	NI	CB	W
Social costs	0	++	++	++	++
Food costs	0	+	--	--	0
Farm income	0	+	--	--	-
State's share of farm income					
Illinois	0	-	-	-	0
Wisconsin	0	-	+	+	+
Income owners of more erodible farmland	0	---	0	---	0
Erosion					
Corn Belt	0	--	---	---	-
Illinois	0	---	+	---	+
Wisconsin	0	0	---	---	---
Conservation practices					
Conservation tillage	+++*	+++	+++	+++	+++
Contouring	0	+	++	++	+
Terracing	0	+	++	++	+
No change:	0				
very small increase:	+				
small increase:	++				
increase:	+++				
very small decrease:				-	
small decrease:				--	
decrease:				---	

*This is a comparison to current conditions.

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decreases in expenditures to consumers with policies NI and CB, under policy I, there would be relatively small increases in returns to landowners and in consumer expenditures. Under policy W, returns to landowners in Wisconsin would decrease, while consumer expenditures would remain unchanged.

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2. Taken together with the results of Seitz et al. (1978), the results of this study imply that the economic impacts on producers may be rather small. Under policy I, there would be relatively small increases in returns to landowners and in consumer expenditures. Under policy W, returns to landowners in Wisconsin would decrease, while consumer expenditures would remain unchanged. While the price effects and costs of soil-erosion controls would bring about relatively large decreases in returns to landowners and decreases in consumer expenditures with policies NI and CB, as compared to policies I and W, the overall impacts of the two policies are small.

3. The allocation of crops to different soil types when a soil loss restriction was applied appeared to have an important impact on (1) changes in crop production and prices and (2) farm income and consumer expenditures. The impacts on farm income and consumer expenditures estimated under this work were not consistent with Seitz et al. (1978). If corn price decreased, as it did under policies NI and CB, farm income and food costs would decrease. If corn price increased, as it did under the 6.72 MTHY (3-TAY) restriction under Seitz et al. (1978), the opposite would occur. The direction of change in corn prices depended on a complex interaction of the initial allocation of crops when soil-loss restrictions were applied and the changes in crop production and shifts of crops among regions that occurred after the application. The price impacts on farm income and consumer expenditures were due to the revenue effects of an inelastic demand for food. The price of soybeans consistently increased (and production decreased) because it was the most erosive of the major crops grown in the Corn Belt.

4. The impact of the policies on Illinois' and Wisconsin's comparative advantage in agricultural production (that is, their shares of producers' surplus) was relatively small because the price impacts of these policies affected both those areas that applied a soil-loss restriction and those that did not. Shifts of production between regions and erosion-control costs seem to have had some minor effect on comparative advantage. Crop shifts, however, can slightly improve the comparative advantages of some states, such as Wisconsin, and slightly degrade the comparative advantage of others, such as Illinois.

5. The impacts of the policies on farm income within a state were unevenly distributed. Under policies I and CB, there was a large burden on a relatively small group in Illinois, the owners of erodible land. Since more erodible soils are concentrated in southern Illinois than in the northern part of the State, southern Illinois would be more adversely affected than other State areas if a soil-loss restriction were applied in Illinois. Under some circumstances, if crop prices increased, the returns to owners of less erodible land would increase in a state where erosion controls were applied, which occurred in Illinois under policy I. Also, crop shifts and price changes would affect returns in areas that did not apply soil-loss restrictions.

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6. Soil loss would be reduced by changing crop patterns, tillage practices, and conservation practices with all policies. With policies I, NI, and W, soil loss would decrease in areas that applied soil-loss restrictions but would increase, to a lesser degree, in areas that did not. Coordination of the different states' policies would minimize these transfers of soil loss between states. Total soil loss, however, would still decrease if one state enacted a soil-erosion-control policy while others did not, and the income impacts on agriculture in that state would not be large.

7. The results of this research predict that economic incentives will encourage farmers to adopt conservation-tillage methods and reduce soil loss. These results agree with those of Seitz et al. (1978). Government action through financial assistance or soil-loss restrictions would therefore not be needed to bring about the decrease in soil loss associated with the adoption of conservation tillage. Although conservation tillage may not always meet SCS soil-loss goals, educational programs emphasizing its financial advantages, as well as its soil-conservation aspects, could be instituted and continued to encourage its adoption.

8. Another important implication of this work is that prices and production of crops will change in response to the application of soil-loss restrictions to improve water quality. It is likely that the prices of some crops will increase (and their production decrease) when they are removed from production to prevent soil loss, while the prices of substitute crops will decrease (and production increase). These changes in prices and production, together with the costs of erosion controls, will have an impact on farm income and food costs. To reduce erosion and, hopefully, improve water quality, society will bear a cost, in the short run, because of the costs of applying erosion-control practices and the changes in crop production associated with rotation changes. The price impacts of these controls will affect the way the cost is distributed among producers and between producers and consumers. In the long run, however, it is hoped society will receive benefits in terms of food production because applying erosion controls will maintain soil fertility.

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APPENDIX

Variables

q = rotation

b = conservation practice

c = tillage

d = location

e = resource class

e* = Land Capability Unit (LCU)

e¹ = Land Resource Area (LRA)

f = crop

1 = corn

2 = soybeans

3 = oats

4 = wheat

5 = hay

6 = pasture

7 = erosion

g = commodity purchase

p = phosphorus

k = potassium

L = labor

i = step in demand function

j = maximum soil loss allowed per acre

m = last step in the demand function

AC_{af} = proportion of acreage of rotation a in crop f

aum = animal unit months-acre of pasture

C_{abcde} = cost of production activity (\$/acre) exclusive of labor and fertilization costs

C_{de1} = cost of baling hay in region d in LRA e¹ (\$/ton)

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D_f = requirements for good f

D_{fde}^1 = requirements for good f in region d in LRA e^1

ΔHC = change in harvest cost of corn as yields per acre change (\$/bu)

HP_{de}^1 = transfer of acres of hay to pasture in region d in LRA e^1

h^*g = labor requirements for corn (man hours/bu)

h^1g = labor requirements for baling hay (man hours/ton)

h_{abcdeg} = units of input g required for production activity X_{abcde}

HE_{abcde} = herbicide expenditure per acre of production activity X_{abcde}

IE_{abcde} = insecticide expenditure per acre of production activity X_{abcde}

J = soil-loss restriction

LA_{de} = amount of resource class e in region d (acres)

LAT_{de} = amount of resource class e suitable for terracing in region d

n_{abcdef} = needs for elemental nitrogen by crop f in production activity X_{abcde} (lb./acre)

n_{if} = needs for elemental nitrogen by corn in step i of the corn demand function

nc_{abcdef} = amount of elemental nitrogen supplied to corn by crop f for each acre of production activity X_{abcde} (lb/acre)

P_{nf} = price of nitrogen purchased by good f (\$/lb.)

P_g = price of input g (\$/unit)

Q_{fi} = level of activity of demand step i for good f

Q'_1 = correction activity for corn-harvest cost (bu) (base > actual)

Q''_1 = correction activity for corn-harvest cost (bu) (base < actual)

Q^*_1 = correction activity for corn P, K, L needs (bu) (base > actual)

Q^{**}_1 = correction activity for corn P, K, L needs (bu) (base < actual)

q_{fi} = production of good f at demand step i (bu)

R_g = quantity of input q purchased

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R_{NF} = purchase of nitrogen for good f

r_{fi} = revenue from sales of good f at demand step i (\$)

T_{de1} = hay production in LRA e^1 in region d (tons)

T'_{f1} = transfer nitrogen from good f to corn (lb)

TF_f = transfer column for production of good f

t_{abcde} = proportion of land of production activity t_{abcde} that requires terracing

$t_{abcde} = 1$, if terracing is required

$t_{abcde} = 0$, if terracing is not required

W_{fi} = area under demand curve for product f up through step i

X_{abcde} = amount of production activity (acres)

Y_{abcdef} = production of good per acre of production activity X_{abcde} (at an assumed price)

Z_{abcdej} = soil-loss restriction coefficient

$Z_{abcdej} = 1$, if $Y_{abcde1} > j$

$Z_{abcdej} = 0$, if $Y_{abcde1} < j$

Documentation of Illinois--Corn Belt Model

Objective Function

The objective function maximizes the sum of the areas under the corn and soybean demand curves less all costs incurred in producing corn and soybeans and all production costs of meeting requirements for wheat, oats, hay, and pasture. In essence, the model maximizes producers' and consumers' surpluses and determines a market equilibrium assuming perfect competition in which quantity demanded equals quantity supplied at an equilibrium price. The demand function is incorporated through a series of steps.

Maximize

$$- \sum_a \sum_b \sum_c \sum_d \sum_e C_{abcde} X_{abcde} + \sum_f \sum_i W_{fi} Q_{fi} + \Delta HC_1 Q'_1 - \Delta HC_1 Q''_1 -$$

$$\sum_g P_g R_g - \sum_d \sum_e C'_{de1} T_{de1}$$

(Eq. 1)

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1. The net revenue generated by a market equilibrium is computed by the following equation:

$$- \sum_{a b c d e} \sum_{f i} C_{abcde} X_{abcde} + \sum_{f i} r_{fi} Q_{fi} + \Delta HC_1 Q'_1 - \Delta HC_1 Q''_1$$

$$- \sum_f P_{Nf} R_{Nf} - \sum_g P_g R_g - \sum_{d e l} C'_{del} T_{del} \quad (\text{Eq. 2})$$

2. This equation calculates the production of corn and transfers it through a column to sell corn, to account for changes in corn-harvesting cost, and to account for changes in corn requirements for potassium, phosphorus, and labor.

$$\sum_{a b c d e} Y_{abcde} X_{abcde} - TF_f \geq 0 \quad (\text{Eq. 3})$$

for f = 1 6-1/2"

3. Corn is sold in this equation. A correction factor is applied to account for changes in corn yield that result from decreases in nitrogen fertilizer application that, in turn, result from decreases in the price of corn as more corn is sold.

$$TF_f - \sum_{i=1}^m \frac{100}{Y_{fi}} (q_{fi}) Q_{fi} \geq 0 \quad (\text{Eq. 4})$$

for f = 1

4. In calculating corn-production cost per acre, harvest costs are included for a given quantity of corn production per acre. Per-acre production varies, however, as prices and nitrogen fertilizer applications vary. This equation accounts for changes in corn-harvest costs brought about by changes in per-acre yields.

$$TF_f - \sum_{i=1}^m q_{fi} Q_{fi} - Q''_1 + Q'_1 = 0 \quad (\text{Eq. 5})$$

5. The corn requirements for phosphorus, potassium, and labor are assumed proportional to yields. This equation accounts for changes in requirements as changes in per-acre yields change.

$$TF_f - \sum_{i=1}^m q_{fi} Q_{fi} - Q^*_1 + Q^{**}_1 = 0 \quad (\text{Eq. 6})$$

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6. Soybean production and sales are calculated in this equation.

$$\sum_{a=1}^m \sum_{b=1}^m \sum_{c=1}^m \sum_{d=1}^m \sum_{e=1}^m Y_{abcde} X_{abcde} - \sum_{i=1}^m q_{fi} Q_{fi} \geq 0 \quad (\text{Eq. 7})$$

for f = 2

7. Requirements for the production of oats in the Corn Belt must be satisfied.

$$\sum_{a=1}^m \sum_{b=1}^m \sum_{c=1}^m \sum_{d=1}^m \sum_{e=1}^m Y_{abcde} X_{abcde} \geq D_f \quad (\text{Eq. 8})$$

for f = 3

8. The next equation requires that a certain quantity of wheat be produced in the Corn Belt.

$$\sum_{a=1}^m \sum_{b=1}^m \sum_{c=1}^m \sum_{d=1}^m \sum_{e=1}^m Y_{abcde} X_{abcde} \geq D_f \quad (\text{Eq. 9})$$

for f = 4

9. Acreage in hay in each LRA can be harvested in hay or can serve as pasture.

$$\sum_{a=1}^m \sum_{b=1}^m \sum_{c=1}^m \sum_{d=1}^m \sum_{e=1}^m Y_{abcde} X_{abcde} - T_{de1} - HP_{de1} \geq 0 \quad (\text{Eq. 10})$$

for all d and e¹ and f = 5

10. Requirements for hay in each LRA must be satisfied.

$$T_{de1} \geq D_{fde1} \quad \text{for } f = 5 \quad (\text{Eq. 11})$$

11. Requirements for pasture production in each LRA must be met.

$$\sum HP_{de1} \geq D_{fde1} \quad (\text{Eq. 12})$$

for f = 6, all d and e¹

12. Phosphorus and potassium fertilizer is purchased to meet the requirements for these goods in crop production.

$$\sum_{a=1}^m \sum_{b=1}^m \sum_{c=1}^m \sum_{d=1}^m \sum_{e=1}^m h_{abcde} X_{abcde} - h^*_{g1} Q^*_{g1} + h^*_{g2} Q^*_{g2} - R_g \geq 0 \quad (\text{Eq. 13})$$

for g = P₁K

13. Labor is also purchased to meet needs for crop and hay production.

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$$\sum_{a b c d e} h_{abcdeg} X_{abcde} + \sum_{d e l} h_{g l} T_{de l} - h^*_{g} Q^*_{l 1}$$

$$+ h^*_{g} Q^{**}_{l 1} - R_g \leq 0$$

(Eq. 14)

for $g = < L$

14. Corn nitrogen needs are satisfied by the purchase of nitrogen fertilizer or the use of nitrogen left in the ground by hay or soybeans grown in previous years.

$$\sum_{i=1}^m n_{if} (q_{fi}) Q_{fi} - T'_{21} - T'_{51} - R_{N1} \leq 0$$

(Eq. 15)

for $f = 1$

15. Soybeans and hay, as stated above, can supply nitrogen to corn.

$$\sum_{a b c d e} n_{c} X_{abcde} - T'_{f1} \leq 0$$

(Eq. 16)

for $f = 2,5$

16. Nitrogen needs for the production of oats and hay must be met through the purchase of nitrogen fertilizer.

$$\sum_{a b c d e} n_{abcde} X_{abcde} - R_{Nf} \leq 0$$

(Eq. 17)

for $f = 3,5$

17. Nitrogen needs for the production of wheat must also be met through the purchase of nitrogen fertilizer.

$$n_f T F_f - R_{Nf} \leq 0$$

(Eq. 18)

for $f = 4$

18. All rotations in each resource class in each region are constrained by the acreage of the resource class in the region.

$$\sum_{a b c} X_{abcde} \leq L A_{de}$$

(Eq. 19)

for all d and e

19. Production activities that require terracing must be constrained by the acreage of land in the resource class and region suitable for terracing.

$$\sum_{a b c} t_{abcde} X_{abcde} \leq L A T_{de}$$

(Eq. 20)

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for all d and e with land suitable for terracing

20. The number of steps in the corn and soybean demand curves must be constrained so that no more than two steps are active in each demand function.

$$\sum_{i=1}^m Q_{fi} \leq 1$$

(Eq. 21)

for f = 1,2

Environmental Controls

21. Restrictions on per-acre soil loss were applied in the following manner.

$$\sum_a \sum_b \sum_d \sum_e Z_{abcdej} X_{abcde} \leq 0$$

(Eq. 22)

for a given d, a given e¹, and a given j (the maximum permissible soil loss) if $Y_{abcdef} \geq j$, $Z_{abcdej} = 1$; otherwise $Z_{abcdej} = 0$. When a soil-loss restriction is not active in a region or LRA, the equation is converted to an accounting row.

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